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Japanese Published Unexamined Patent Application (A) No.11-145525, published May 28, 1999; Application Filing No. 9-305259, filed November 7, 1997; Inventor(s): Watabiki Seiji et al.; Assignee: Hitachi Mfg. Inc.; Japanese Title: Manufacturing Method for Piezoelectric Actuators

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# Manufacturing Method for Piezoelectric Actuators

## CLAIM(S)

A method to manufacture a piezoelectric actuator comprising the following steps: a step of producing a green sheet by installing a conductive layer for an internal electrode on both surfaces of the green sheet made of ceramic material having piezoelectric characteristic; a step of forming the green sheet laminate body by successively laminating said green sheets; a step of thermally pressing to produce a pressed body by laminating and integrating by heating said green sheet laminate and by pressurizing it in the lamination direction; a step of thermally cracking and removing a binder contained in said pressed laminate body and of sintering it; a step of forming an insulated layer by alternately covering said internal electrode layers positioned on the side surface of said laminate sintered body with an insulating member; a step of forming an external electrode that is alternately conductive to other internal electrode layers by using said insulation

member; said piezoelectric actuator manufacturing method being characterized in that part of said internal electrode intrudes into said green sheet.

DETAILED DESCRIPTION OF THE INVENTION

(Field of Industrial Application)

(0001)

(Field of Industrial Application)

The present invention pertains to a manufacturing method for a piezoelectric actuator, particularly, to the piezoelectric actuator excellent in bonding strength of bonding boundary between the internal electrode layer of laminate type sintered body and the ceramic layer having piezoelectric characteristics.

(0002)

(Prior Art)

The method to manufacture the prior art piezoelectric actuator is explained below with reference to Fig. 2. Fig. 2 (a) shows a sectional view of a ceramic green sheet 4 having piezoelectric characteristics and internal electrode layers 3 and 5, wherein a green sheet is formed on both surfaces by an electrode material in paste form by a printing method and wherein an internal layer 2 is formed likewise by the printing method on one of the

surfaces of protection layer on the top and bottom surfaces. The internal electrode layer does not intrude into the ceramic green sheet having the piezoelectric characteristics.

(0003)

Fig. 2 (b) shows a sectional view of a laminated sintered body, wherein the green sheets of Fig. 2 (a) are laminated successively and integrating the laminate having the protection layer 1 installed on the top and bottom surfaces by heating and exerting pressure on it in the laminating direction for pressure bonding, and wherein a binder inside the integrated laminate body is removed by thermal cracking and sintering. In the bonding boundary of the internal electrode layer in the sintered body and of ceramic member, the internal electrode layer does not intrude into the ceramic member.

(0004)

Subsequently, the aforementioned internal electrode layer positioned on the side surface of the aforementioned laminate sintered bodies is covered alternately with an insulating material and the external electrodes are formed to be alternately conductive to other conductive layers by covering the aforementioned insulating layers. Thus the piezoelectric actuator is manufactured. The internal electrode layer of the piezoelectric actuator thus

manufactured is not intruded into the ceramic member having the piezoelectric characteristics. There is no publicly known example of piezoelectric actuator wherein an internal electrode layer is installed on both surfaces of the green sheet, but only one example is found in Japanese Published Unexamined Patent Application 07-169999. In this example, after the internal electrode layer is installed on one or both surfaces and dried. Then, 58 sheets of it are laminated and pressure-bonded by heat to manufacture a piezoelectric actuator.

(0005)

The inventors conducted a series of experiments on how to form the internal electrode layer by a printing method and examined in detail on how to improve the bonding strength in the method to form the internal electrode layer. It was found that the bonding strength of each bonding boundary of the piezoelectric actuator manufactured by the lamination method disclosed in the aforementioned patent application was weak in the boundary of the internal electrode layer, i.e., 2a, of Fig. 2 (b) and of the ceramic member. This is because of the fact that wetting of the ceramic member and that of the internal electrode member are poor and because of the fact that the internal electrode layer and the ceramic layer are merely contacting. On the other hand, the bonding strength of the 2b boundary is strong. This is because of

the fact that the internal electrode layers are contacting on the metal surface and the wetting of both is extremely excellent.

(0006)

The present invention attempts to present a method to manufacture a piezoelectric actuator excellent in durability by laminating multiple internal electrode layers on both surfaces of the green sheet made of ceramic member having piezoelectric characteristics and by reinforcing the bonding strength of the boundary between the ceramic member and the internal electrode layer of the piezoelectric actuator.

(0007)

(Means to Solve the Problems)

In the method for manufacturing the piezoelectric actuator of the present invention, on both surfaces of the ceramic green sheet having the piezoelectric characteristics, the green sheet on which the internal electrode layer formed by printing the conductive material in pasts form is laminated, pressure bonded at a temperature at which the binder in the green sheet is fluidized and, subsequently, the binder contained in the green sheet is removed and sintered; this piezoelectric actuator being characterized in that part of the internal electrode layer intrudes into the ceramic member having the piezoelectric characteristics and forms a complex structure. In the way of

intrusion, it forms a net structure, generating mechanical bonding, which results in reinforcing the bonding strength in the boundary. Accordingly, the durability and performance of the piezoelectric actuator manufactured for the internal electrode layer to intrude into the ceramic member is many times more excellent than that of the actuator manufactured by attaching the internal electrode layer that is not intruding into the ceramic member.

(0008)

(Embodiment Examples)

(Embodiment Example 1)

The embodiment example of the method to manufacture the piezoelectric actuator of the present invention is explained below with reference to the figures. Fig. 1 shows the main components in the manufacturing method for the laminate type piezoelectric actuator in the first embodiment example of the present invention. The protection layer 1 and the green sheet 4 are the green sheets having the piezoelectric characteristics. The internal electrode layers, 2, 3, 5, attached to one of the surfaces of the protection layer 1 and to both surfaces of the green sheet are primarily made of metal excellent in conductivity and partially contain a glass component. The internal electrode layer is provided by the printing method. In this case,

if the density of the green sheet is low, the electrode layer partially intrudes into the voids of the green sheet and forms a complex structure.

(0009)

After the green sheet provided with the internal electrode layer is dried, 50 sheets of this green sheet shown in Fig. 1 are laminated by laminating the protection layer on the top and the bottom surfaces to make the laminate body. In the figure, however, the number of the layers in the laminating direction is omitted. The laminate body was heated to 130℃, and pressure bonded to integrate it at 10 MPa. Subsequently, air was supplied into a tubular furnace, and after the laminate body was heated to 850℃ to remove the binder contained in the green sheet by thermal cracking, it was sintered in an oxidized atmosphere at 1260℃. It goes without saying that in the laminate type sintered body also, a complex structure layer was formed in the part of the internal electrode layer and in the part of bonding boundary surface 1a of boundaries 8’ and 9’ of the ceramic member having the piezoelectric characteristics. The thickness of the internal electrode 2 μm in the protection layer including the complex structure layer, and the thickness provided to one of the surfaces of the ceramic member is 1 μm.

(0010)

Subsequently, the aforementioned conductive layers positioned on the side surface of the sintered laminate body omitted from the figures were alternately covered with an insulating member, and the external electrode was formed to conduct to other conductive layers alternately by covering with the aforementioned insulating member. The reliability test was conducted for the laminate type piezoelectric actuator and the prior art piezoelectric actuator (the one wherein the internal electrode layer is not intruded into the ceramic layer). An example of the test is explained below.

(0011)

The test sample had 60 layers, provided that the ceramic layer 4' in Fig. 1 (b) is 120 μm thick, perceiving the internal electrode layers 2' and 3' as 1 layer, that the top and bottom protection layers 1' are 2 mm and 4 mm thick, respectively, that the sectional shape perpendicular to the direction of changed position is 5 mm x 5mm, and that the length of the changed position direction is 18 mm. The ceramic layer 4' having the piezoelectric characteristics had an oxidized perofskite structure in which part of Pb in PZT (Pb 0.64, $ZrO_2$ 0.24, $TiO_2$ 0.11) was substituted with Sr, and the internal electrode layers 2', 3' were silver –palladium mixed powder electrodes containing Ag 65% and Pd 35%.

(0012)

The insulator not shown in the figures is made of borate glass and the external electrode layer was made of silver conductor. For the aforementioned protection layer covering the outer periphery, silica group glass was used. The piezoelectric actuator thus manufactured was used by 10 units as the test samples, and the activation test was conducted by using the following parameters. The activation parameters: load 200 N; rectangular wave driving by frequency 100 Hz; about 300 – 1500 V voltage charge; positional change 18 μm. The number of repetitions of activation until the internal electrode layer and the ceramic layer were separated in the boundary, causing the destruction of the ceramic layer, and making it impossible to produce the positional change 18 μm was confirmed. The result is shown in Fig. 3.

(0013)

The ratio at which the ceramic layer was not destroyed by 5 x 10 times of operations in the piezoelectric actuator of the comparative example was 0%. More specifically, in the case of the comparative example, the positional change 18 μm of laminate body was not found. Conversely, with the piezoelectric actuator of the embodiment example 1, the ratio at which the ceramic layer was not destroyed after $1 \times 10^9$ times of operations was as high as 65%. Accordingly, with the piezoelectric actuator of the present

invention, the number of activations and driving durability until the ceramic layer was destroyed could be increased.

(0014)

(Embodiment Example 2)

By using the method to form the internal electrode on both surfaces of the green sheet made of ceramic material having the piezoelectric characteristics, the laminate type piezoelectric actuator was formed by using a 0.5 μm thickness for one of the internal electrode including the complex structure formation layer and 1.5 μm m for the thickness of the other internal electrode, as in the embodiment example 1. In the order of forming the internal electrodes, the thicker one was formed first. This piezoelectric actuator also was evaluated in the same way as in the embodiment example 1. The result is shown in Fig. 3. The piezoelectric actuator of embodiment example 2 showed the same result as that of the embodiment example 1. In addition, 6 and 7’ the boundary between the internal electrode layer and the ceramic layer with the piezoelectric characteristics, in which the internal electrode is not intruded; 8 and 9 show the boundary between the internal electrode layer and the ceramic layer with the piezoelectric characteristics, wherein part of the internal electrode layer is intruded.

(0015)

(Advantage)

According to the present invention, the internal electrode layer is partially intruded into the green sheet made of ceramic material having the piezoelectric characteristics. Therefore, in the laminate type sinter body, the internal electrode layer is partially intruded into the ceramic layer, so the bonding strength of the bonding boundary between the internal electrode layer surface and the ceramic layer surface is increased more than the one made by the prior art. By this, there is not separation of boundary that occurs by stress generated at the time of driving the piezoelectric actuator, and the destruction of the ceramic layer can be prevented. Accordingly, with the piezoelectric actuator of the present invention, the number of activations until the ceramic layer is destroyed and the driving durability performance can be increased.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a sectional view of the protection layer indicating the steps of manufacturing the piezoelectric actuator as the embodiment example of the present invention.

Fig. 2 shows a sectional view o the protection layer indicating the steps of manufacturing the prior art piezoelectric actuator.

Fig. 3 shows a characteristic graph indicating the relationship between the number of repetitive activations of the piezoelectric actuator and the ratio at which the ceramic layer of the piezoelectric actuator was not destroyed.

1,1. protection layer

1a, 1b. bonding boundary

2, 2’, 3, 3’, 5. internal electrode layer

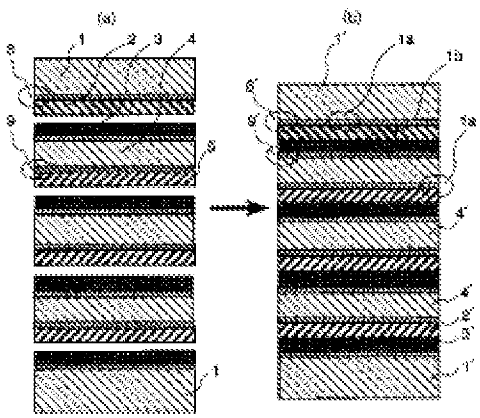
4. green sheet

4’. ceramic layer

6, 6’, 7, 7’, 8, 8’, 9, 9’. Boundary

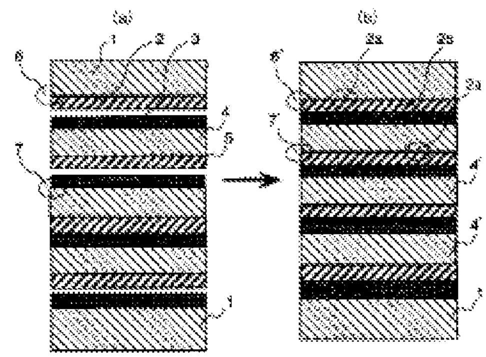
【図1】

図 1



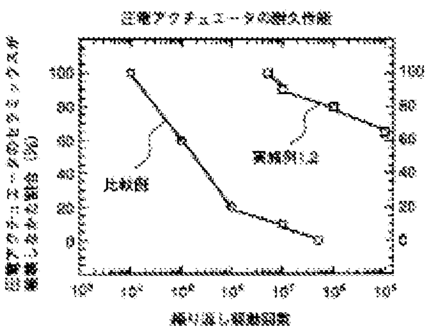

【図2】

図 2




【図3】

図 3




Translations
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